SOLAR ENERGY

Gianfranco Sorasio

e-mail: sorasio@iscat.com

T :: 0039 0175 44648
T :: 0039 333 6056264

T :: 00351 9144 03486

ISCAT
Innovative Science
Application and Technology

Il contenuto di questa presentazione è parte integrante del corso di Fisica dell'energia dell'Università Tecnica di Lisbona, IST Portogallo. Il reggente della cattedra è il Prof. Gianfranco Sorasio, A.D del Centro Ricerche ISCAT s.r.l.

Novembre 2006, Gianfranco Sorasio :: Energia solare parte I

OUTLOOK

- Visione generale del mercato fotovoltaico in Europa
- Origine della radiazione solare e effetto dell’assorbimento dell’atmosfera sullo spettro della radiazione
- Radiazione diretta, diffusa e Albedo
- Coodinate di posizione solare e calcolo delal radiazioni incidente
- Inclinazione ottimale dei pannelli fotovoltaici
- Funzionamento delle celle solari :: il silicio come semiconduttore
- Esame delle caratteristiche elettriche dei pannelli Sanyo
- Conclusioni e referenze

Photovoltaic :: news

Solar power is more in demand than ever before.

Photovoltaic power plants are built in ever greater numbers all over the world to transform sunlight into electrical power that **will be able to compete with conventionally generated electricity in the medium term.**

At the end of the particularly hot month of July 2006, the daily rate for peak-hour electricity from coal, gas and nuclear power plants reached a **high of 54 euro cents per kilowatt** hour at the German electricity stock exchange (Leipzig) and thus **exceeded the price for generating solar power for the first time.** In Germany solar power is compensated with 40,6 to 51,8 euro cents per kilowatt hour

The fact is that the price of electricity is growing so fast that the photovoltaic solar panels are already competitive in some region or periods of the year.

Market situation

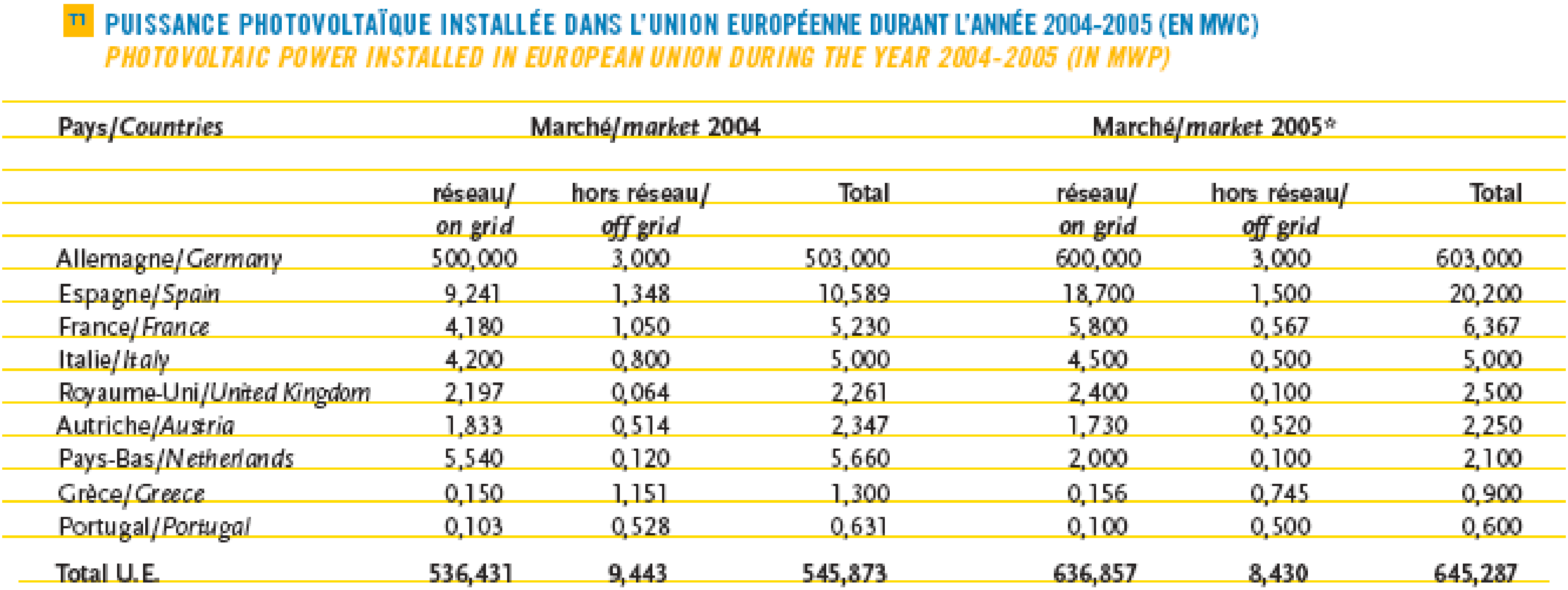
The Photovoltaic market is in strong expansion

In 2005 the total installed PV system in EU reached the 1793,5 MWp.

The 2005 EU market was of about 645 MWp (+18,2%).

The problem was that, due to the shortage of silicon, they could not produce more photovoltaic modules.

EU installed power



T1 PUISSANCE PHOTOVOLTAÏQUE INSTALLÉE DANS L'UNION EUROPÉENNE DURANT L'ANNÉE 2004-2005 (EN MWC)

PHOTOVOLTAIC POWER INSTALLED IN EUROPEAN UNION DURING THE YEAR 2004-2005 (IN MWP)

Pays/*Countries*	Marché/*market* 2004			Marché/*market* 2005*		
	réseau/ *on grid*	hors réseau/ *off grid*	Total	réseau/ *on grid*	hors réseau/ *off grid*	Total
Allemagne/*Germany*	500,000	3,000	503,000	600,000	3,000	603,000
Espagne/*Spain*	9,241	1,348	10,589	18,700	1,500	20,200
France/*France*	4,180	1,050	5,230	5,800	0,567	6,367
Italie/*Italy*	4,200	0,800	5,000	4,500	0,500	5,000
Royaume-Uni/*United Kingdom*	2,197	0,064	2,261	2,400	0,100	2,500
Autriche/*Austria*	1,833	0,514	2,347	1,730	0,520	2,250
Pays-Bas/*Netherlands*	5,540	0,120	5,660	2,000	0,100	2,100
Grèce/*Greece*	0,150	1,151	1,300	0,156	0,745	0,900
Portugal/*Portugal*	0,103	0,528	0,631	0,100	0,500	0,600
Total U.E.	536,431	9,443	545,873	636,857	8,430	645,287

The expected production in 2010 of 10,4 gigawatt (530% growth versus 2005) at a turnover of 57,6 billion euro and a pre-tax profit of 21,6 billion euro.

THE SUN

SOLAR RADIATION

The sun provides more energy at the Earth surface in 1 hour than we use in one year (all the books on PV write so).

The sun is a ball of fire, we have fusion of Hydrogen and Helium and many other components ... as a results, the sun is like a ball of fire at about 5800 K.

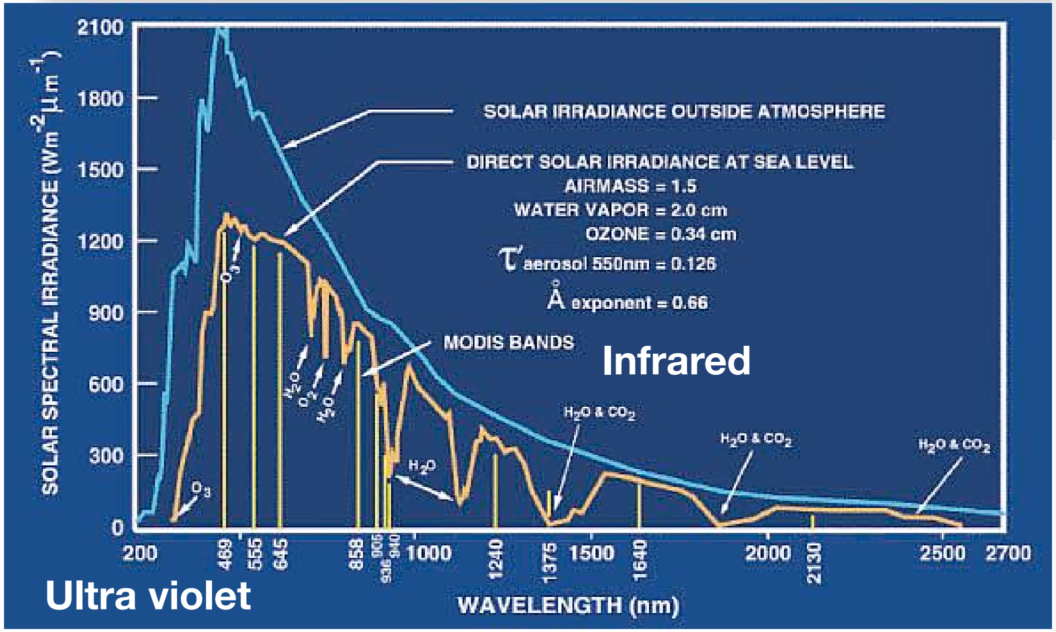
$$W_\lambda = \frac{2\pi h c^2 \lambda^{-5}}{e^{\frac{hc}{\lambda k T}} - 1}$$

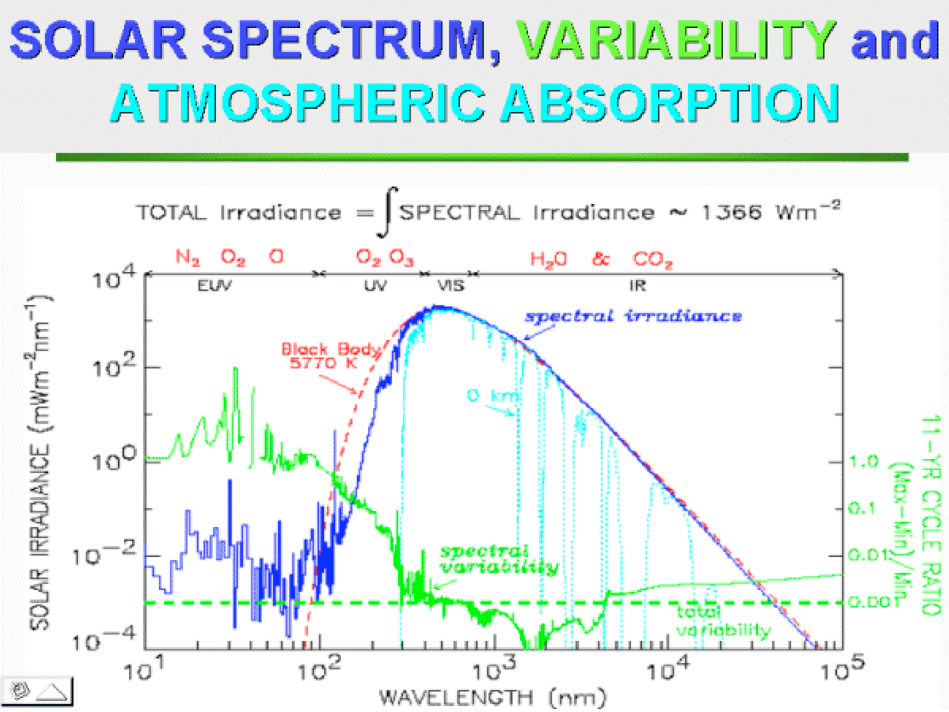
w/m^2/unit wavelength in meters

h Planck's constant

k is the Boltzmann's constant

THE SUN AND THE ATMOSPHERE




SOLAR SPECTRUM, VARIABILITY and ATMOSPHERIC ABSORPTION

The solar radiation outside the atmosphere is about P = 1367 W/m^2

Sunlight can be: direct or diffuse.
The light reflected by Earth is called Albedo

ATMOSPHERIC ABSORPTION

Different molucules absorb various parts of the spectrum:

- Vater vapour and CO2 absorb mainly visible linght and infrared (that is why the earth is warming up).

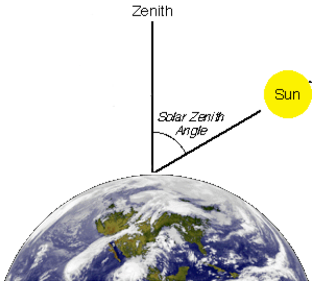
- Ozone absorb mainly the ultra Violet part of the spectrum. That is why the Ozone layer is so important to shield Earth from the sun radiation.

The degree of absorption varies with the amount of atmospheric mass that the radiation must go through.

AIR MASS :: I

The path length is generally compared with a vertical path length to sea level, which is designed **air mass = 1 (AM1)**

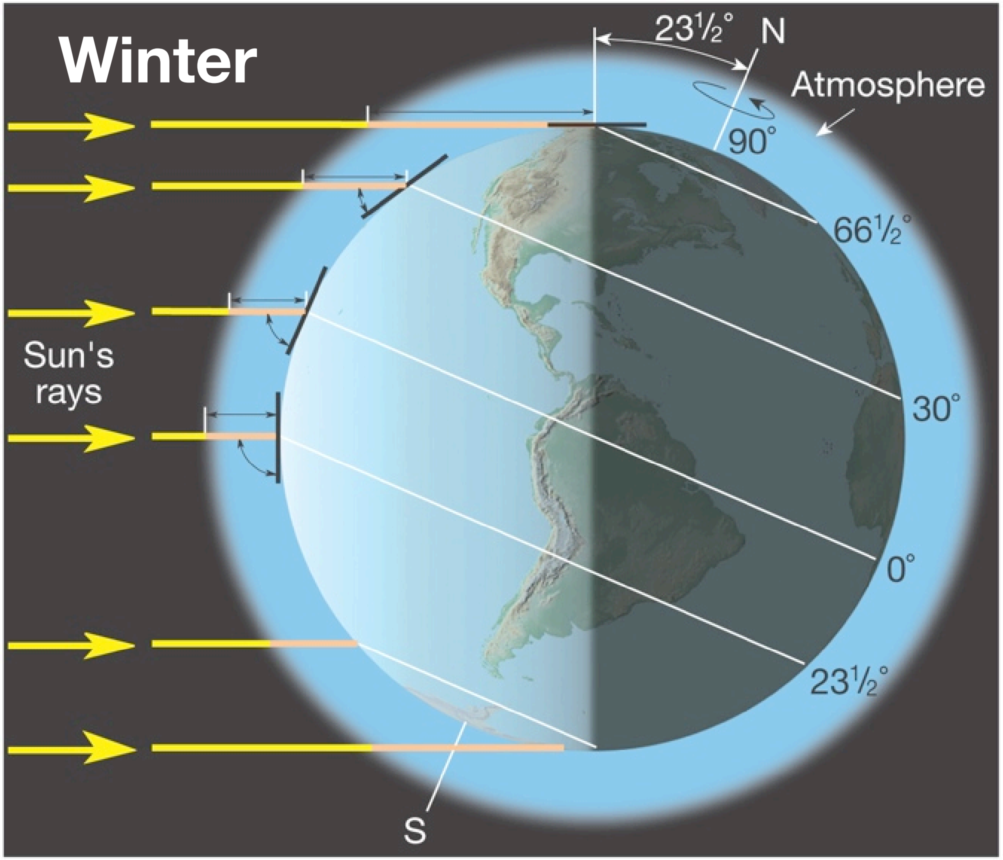
The air mass through which radiation passes is proportional to the zenith angle



The Intensity of the solar radiation is reduced as

$$I = 1367 \times (0.7)^{AM}$$

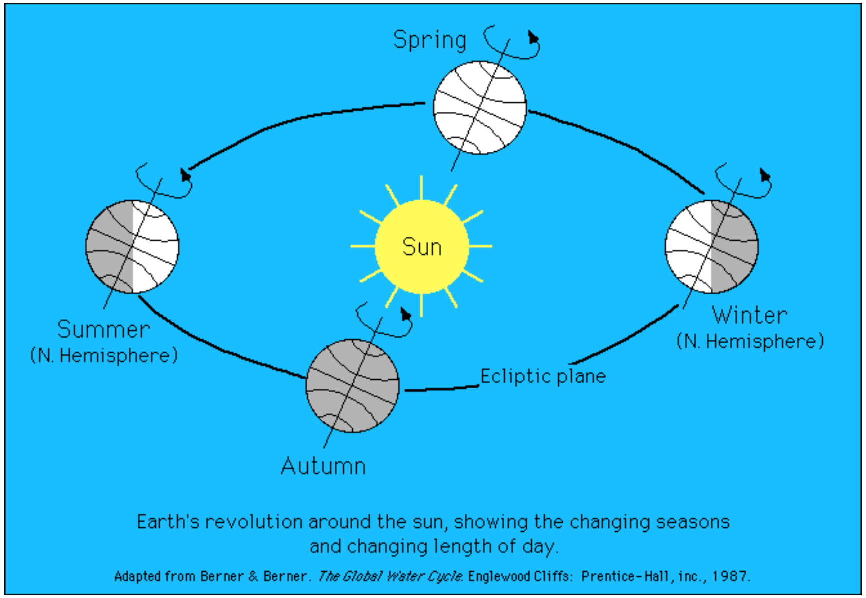
Where I_0 = 1367 W/m^2 is outside the atmosphere. For AM = 1, I = 1000 W/m^2



AIR MASS :: II

The given equation is obvious when AM =1 but does not hold for other air masses.
In fact, a much better fit is given by the form:

$$I = 1367 \times (0,7)^{AM^{0,678}}$$



Earth's revolution around the sun, showing the changing seasons and changing length of day.

Adapted from Berner & Berner. *The Global Water Cycle.* Englewood Cliffs: Prentice-Hall, inc., 1987.

All the solar cells and PV modules are tested and certified at the Standard Test Conditions which are : spectrum air mass AM 1.5, Irradiance I = 1000 W/m^2 and cell temperature of 25 °C. Very inconsistent data ...

$$I = 1367 \times (0,7)^{1,5^{0,678}} = 854\, W/m^2$$

Orbit of the Earth

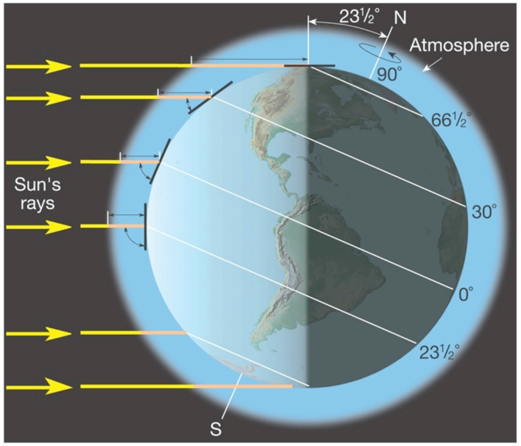
The distance from the sun is given by:

$$d[m] = 1,5 \times 10^{11} \left\{ 1 + 0,017 \sin\left[\frac{360(n-93)}{365}\right] \right\}$$

Where n = 1 is the first of January.

The polar axis of the Earth is inclined by an angle of 23,45° to the plane of the Earth orbit around the sun.

The first day of summer the sun is vertically above the tropic of Cancer at 23,45° Lat. Nord.

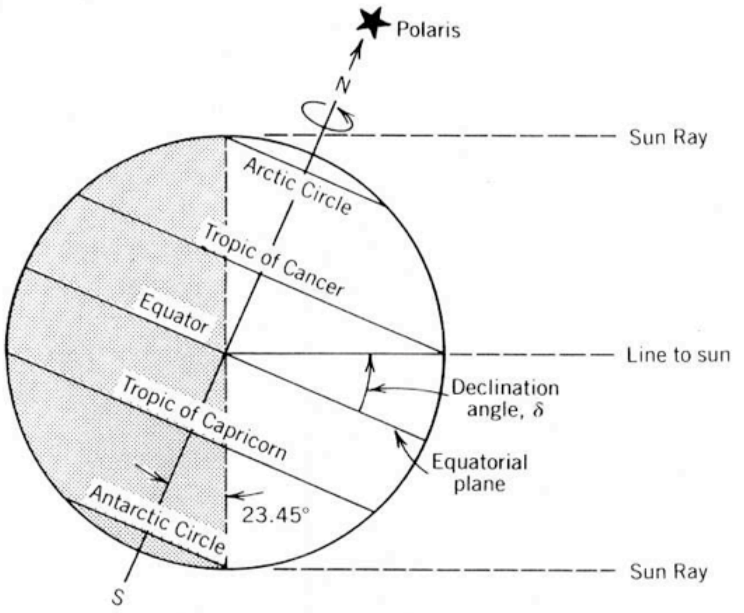


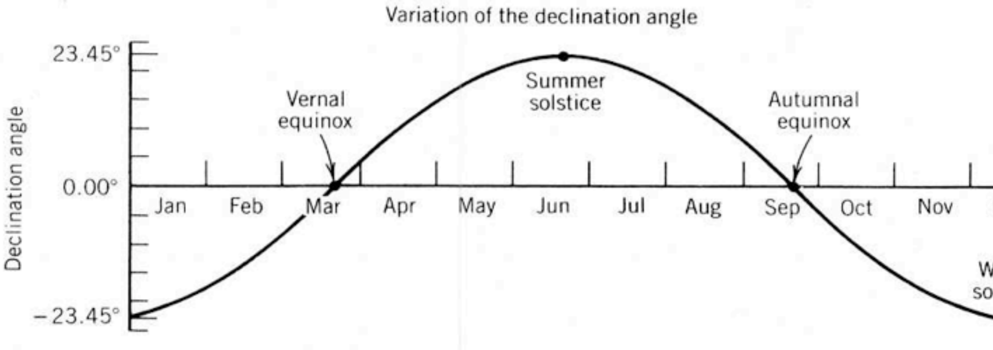
Declination angle

The first day of summer the sun is vertically above the tropic of Cancer at 23,45° Lat. Nord.

$$\delta = 23,45^\circ \sin\left[\frac{360(n-80)}{365}\right]$$

It is positive when the Sun is above the equator and negative when is below (hystorical reasons)





Zenith angle

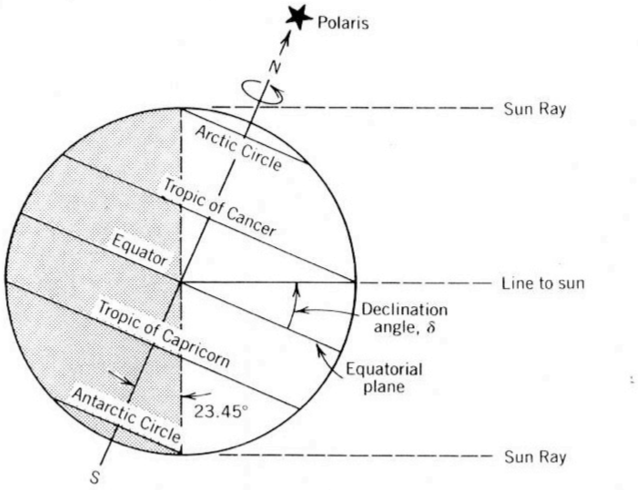
The zenith is a line perpendicular to the Earth surface (straight up). The Zenith angle is defined as the angle between the sun and the zenith.

Clearly the zenith angle and the declination are correlated. At noon, the sun is at its maximum and the zenith angle and declination are the same.

If we define with Φ the latitude of a given place, then we have that at noon the zenith angle is :

$$\theta_z = \phi - \delta$$

The complement of the Zenith angle is called solar altitude α, angle between the horizon and the incident solar beam.



Azimuth angle

The air mass in the path length of the sun beam is proportional to the cosecant of the solar altitude α, such that

$$\boxed{AM = AM(90^{\circ}) \csc \alpha}$$

The angular deviation of the sun from directly south is called azimuth angle Ψ and can be either East or West.

The hour angle respect for any given day, in a 24 hours clock is:

$$\boxed{\omega = \frac{12 - T}{24} \times 360^{\circ} = 15(12 - T)^{\circ}}$$

Where T is in hours respect to midnight.

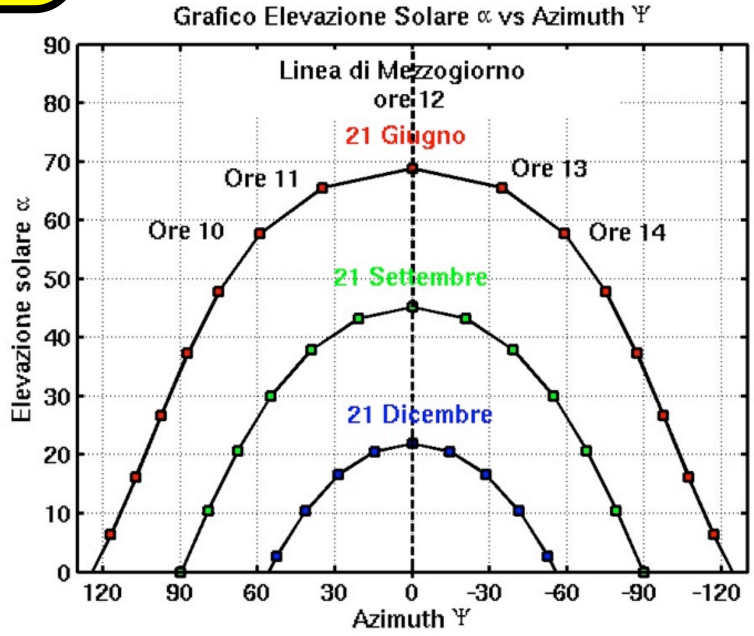
Position of the sun

If we know the latitude Φ, the declination angle δ and the hour we can calculate the position of the sun as:

$$\sin\alpha = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega$$

$$\cos\Psi = \frac{\sin\alpha\sin\phi - \sin\delta}{\cos\alpha\cos\phi}$$

There are much precise equations to find the position of the Sun, but they are not of relevance for PV applications.

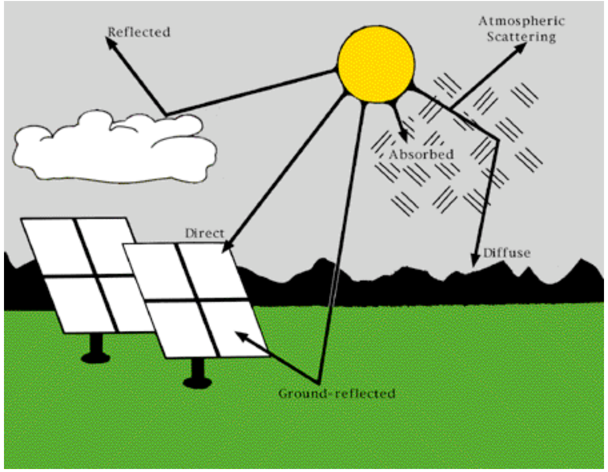


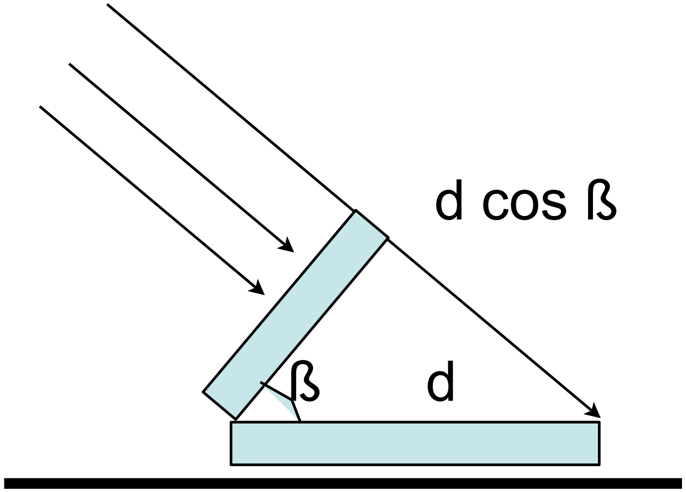
Saluzzo, 44° 38’ 50” N

Measuring sunlight

The pyranometer is designed to measure the global radiation, which is the sum of direct + diffuse radiation.

It is usually mounted horizontally and is designed to respond to all the wavelengths.





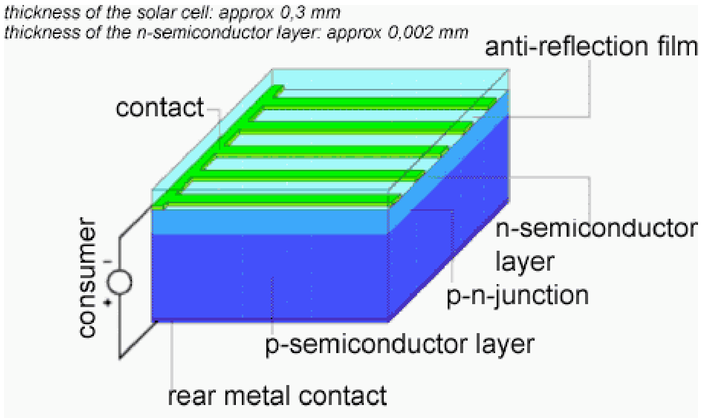
THE PV CELLS

Phisics :: I

Conversion of radiant energy into electrical energy can be acchieved with the use of semiconductor materials.

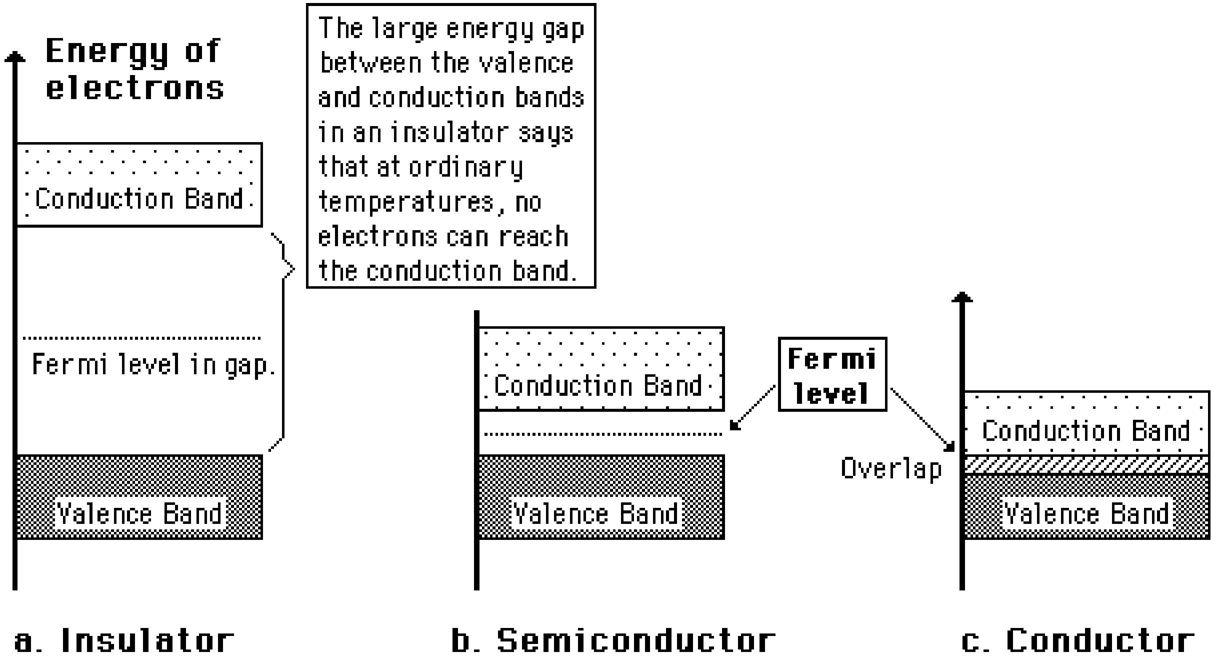
Electron excitation by light enhances the conductivity.

Having a lot of electrons going around is not enough to produce electricity. We need a field to separate them.



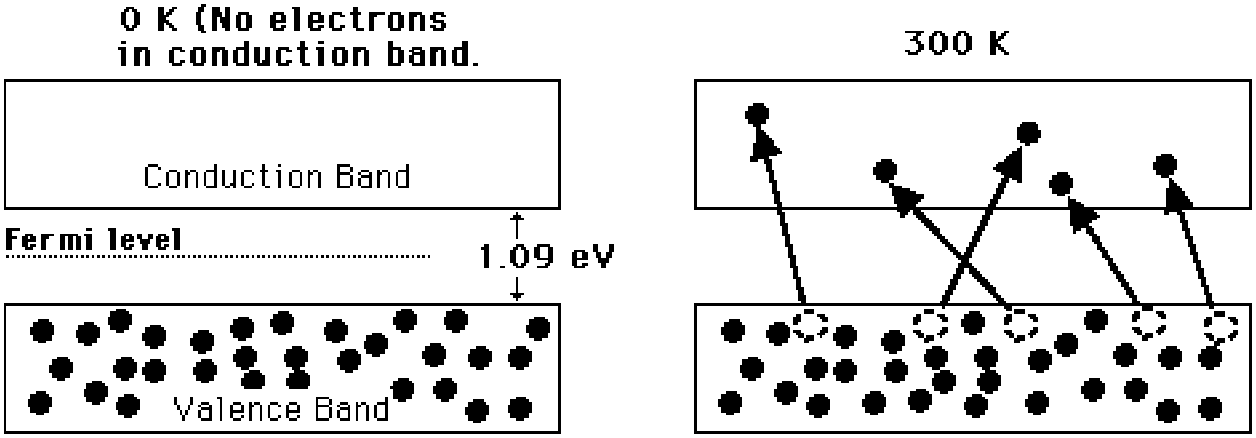
The electrons move from the p-type to the n type while the holes move in the reverse direction. If they reach the boundaries than we have a current: electricity.

Physics :: II


Energy of electrons
The large energy gap between the valence and conduction bands in an insulator says that at ordinary temperatures, no electrons can reach the conduction band.
Conduction Band
Fermi level in gap.
Valence Band
Conduction Band
Valence Band
Fermi level
Overlap
Conduction Band
Valence Band
a. Insulator
b. Semiconductor
c. Conductor

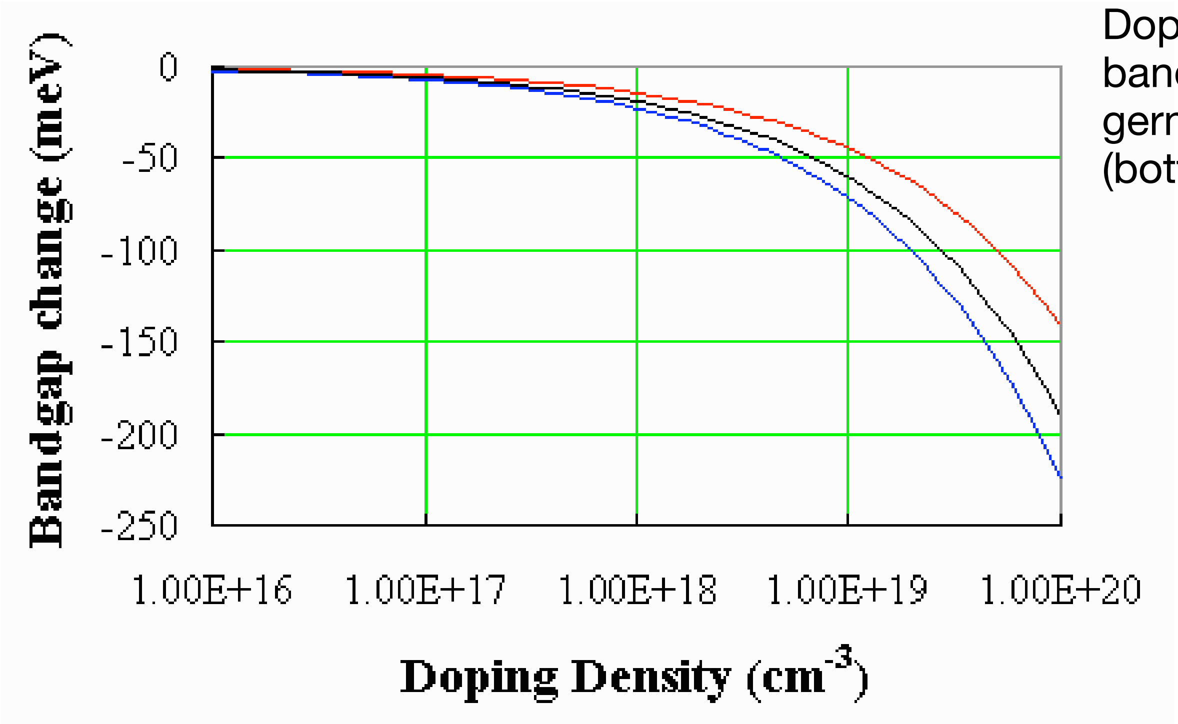
SEMICONDUCTOR

The Si has 4 electrons in the 3s band (all the other are full). The 3s and 3p bands are quite close (~1 eV), and when the temperature increases the electrons can jump in the conduction band.



Doping :: n tipe

If we dope Si with a material with higher Z (phosphorous), than the additional electrons will occupy a descrete level above the valence band, just below the conduction band. negative type



Doping dependence of the energy bandgap of GaAs (top/red curve), germanium (black curve) and silicon (bottom/blue curve).

PV - cells

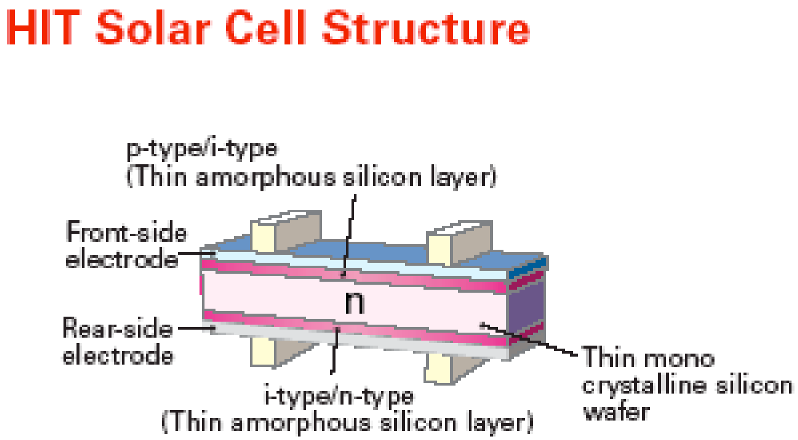
If we dope Si with a material with lower Z (Al), then we create electron vacancies or “holes”. There is a new level called acceptorr level. p- type.

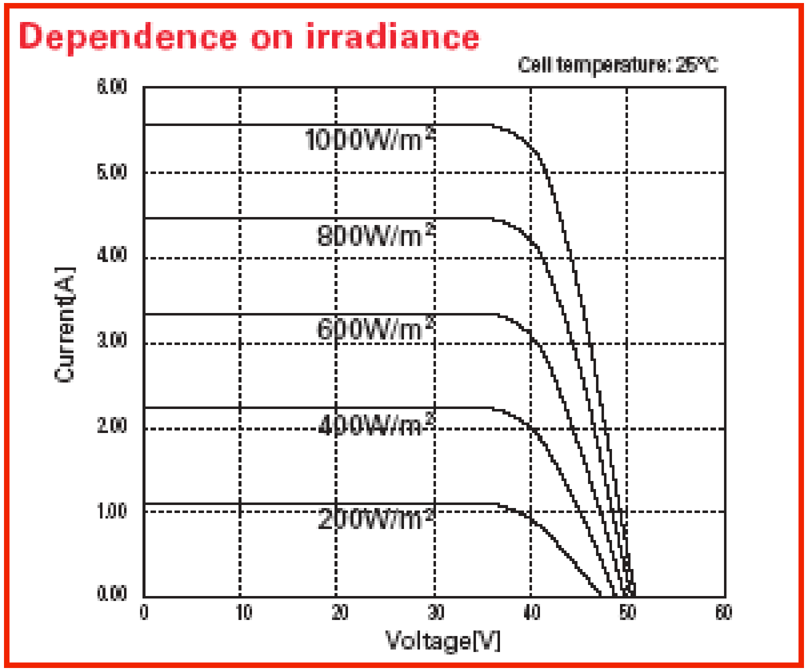
When electrons are excited from the Si, they actually go into the acceptor level, and not into the conduction band.   We can treat holes just as positive particles.

In a p-n junction, there are a lot of electrons in the n-type semiconductor and a lot of holes in the p-type. The electrons flow from n to p type.
They build up a surplus of positive charge in the n-type material, and a surplus of negative charge in the p-type material. This charge separation induces the formation of a static electric field that prevents any further charge build up.

When light hits the material, than we have a net flow of electrons from the p-type to the n-type material. This currents is electricity.

Solar cell :: Sanyo

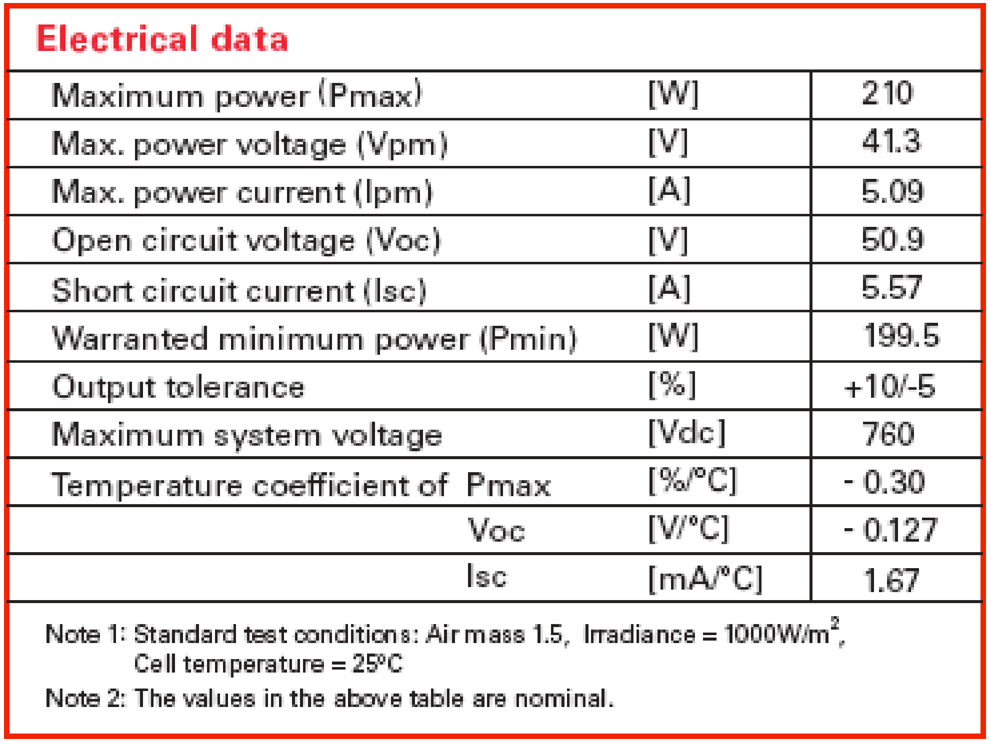

HIT Solar Cell Structure


Dependence on irradiance

The PV cell has a very peculiar behaviour, which is highly nonlinear.

While the Voltage V of the maximum power is almost constant, the currents varies strongly.

Sanyo HIP

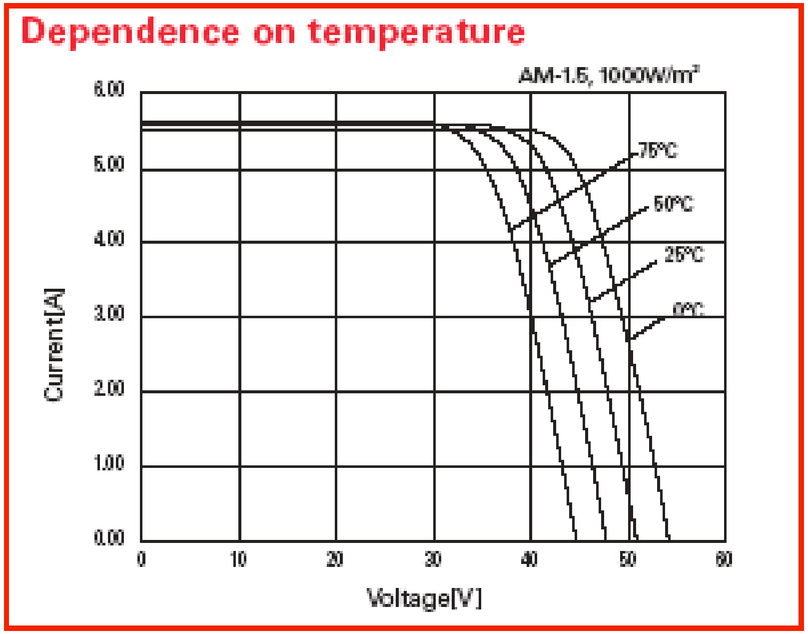


Electrical data

Maximum power (Pmax)	[W]	210
Max. power voltage (Vpm)	[V]	41.3
Max. power current (Ipm)	[A]	5.09
Open circuit voltage (Voc)	[V]	50.9
Short circuit current (Isc)	[A]	5.57
Warranted minimum power (Pmin)	[W]	199.5
Output tolerance	[%]	+10/-5
Maximum system voltage	[Vdc]	760
Temperature coefficient of Pmax	[%/°C]	- 0.30
Voc	[V/°C]	- 0.127
Isc	[mA/°C]	1.67

Note 1: Standard test conditions: Air mass 1.5, Irradiance = $1000 W/m^2$,
Cell temperature = 25°C

Note 2: The values in the above table are nominal.



Dependence on temperature

References

Photovoltaic Systems Engineering, Roger A. Messenger and Jerry Ventre, Second Edition, CRC Press, London 2004.

Renewable Energy, its physics, engineering, environmental impacts, economics and planning, Bent Sorensen, Elsevier Academic Press, 2004.

Principels of Solar Engineering, D. Yogi Goswami, Frank Kreith, Jan F. Kreider, Taylor and Francis Publ., London, 1999.